

Neutrino Masses from Fine Tuning

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Abstract

We present a new approach for generating tiny neutrino masses. The Dirac neutrino mass matrix gets contributions from two new Higgs doublets with their vevs at the electroweak (EW) scale. Neutrino masses are tiny not because of tiny Yukawa couplings, or very heavy ($\sim 10^{14}$ GeV) right handed neutrinos. They are tiny because of a cancelation in the Dirac neutrino mass matrix (fine tuning). After fine tuning to make the Dirac neutrino mass matrix at the 10^{-4} GeV scale, light neutrino masses are obtained in the correct scale via the see-saw mechanism with the right handed neutrino at the EW scale. The proposal links neutrino physics to collider physics. The Higgs search strategy is completely altered. For a wide range of Higgs masses, the Standard Model Higgs decays dominantly to $\nu_L N_R$ mode giving rise to the final state $\bar{\nu}\nu\bar{b}b$, or $\bar{\nu}\nu\tau^+\tau^-$. This can be tested at the LHC, and possibly at the Tevatron.

1 Introduction

In the past decade, the existence of tiny neutrino masses of the order of one hundredth to one tenth of an electron volt has been firmly established through atmospheric, solar and reactor neutrino experiments [1][2][3]. These masses are a million or more times smaller than the corresponding charged lepton masses. While the quark and charged lepton masses span many orders of magnitude, the neutrino masses do not. The square roots of the neutrino mass square differences, as obtained from the neutrino oscillation experiments, lie within a factor of six of each other. Also the quark mixing angles are very small, whereas two of the neutrino mixing angles are large [4]. These observations have led to several unanswered questions. Why are the neutrino masses so small compared to the corresponding charged lepton or quark masses? Why is there such a large hierarchy among the charged fermion masses, while there is practically no hierarchy among the neutrino masses? Also, unlike the quark sector why are the mixing angles in the neutrino sector large? Another related

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fundamental question is whether neutrinos are Majorana or Dirac particles, and whether the light neutrino spectrum exhibit a normal hierarchy or an inverted hierarchy.

The most popular idea proposed so far for understanding the tiny neutrino mass is the famous see-saw mechanism [5]. One postulates the existence of very massive Standard Model (SM) singlet right handed neutrinos with Majorana masses of the order of $M \sim 10^{14}$ GeV. The Yukawa couplings of the left-handed (LH) neutrino to these heavy right-handed (RH) neutrinos then gives a Dirac mass of the order of the charged lepton masses, m_l . As a result, the left-handed neutrino obtains a tiny mass of the order of m_l^2/M . Although there are several indirect benefits for its existence, there is no direct experimental evidence for such a heavy particle. The mass scale is so high that no connection can be made with the physics to be explored at the high energy colliders such as the Tevatron and the LHC. It is important to explore other possibilities to explain the tiny neutrino masses. Also, the see-saw mechanism does not naturally lead to close values of the neutrino masses as observed experimentally, though such close masses can be arranged with the appropriate choice of the right handed Majorana sector.

Recent astrophysical observation requires a tiny but non-zero value of the cosmological constant, $\Lambda^{1/4} \simeq (10^{-4} \text{ eV})$. This value is surprisingly close to the value of the light neutrino masses required from the neutrino oscillation experiments, $\simeq 10^{-2}-10^{-1} \text{ eV}$. It has been exceedingly difficult to derive such a tiny value of the cosmological constant, and there is some acceptance that it may be fine tuned. The idea of Higgs mass also being fine tuned has been explored leading to the so called ‘‘Split Supersymmetry’’ [6] with interesting implications at the TeV scale that can be explored at the LHC. Neutrino masses being in the same ballpark as the cosmological constant, it is not unreasonable to assume that their values are also fine tuned. The objective in this project is to adopt this philosophy, build a concrete model realizing this scenario, and explore its phenomenological implications, especially for the LHC.

In this work, we present a model in which the light neutrinos get their masses from the usual see-saw mechanism, except the right handed neutrino masses are at the EW scale. The neutrino Dirac masses get contributions from two different Higgs doublets with their vacuum expectation values (vevs) at the electroweak scale. The neutrino masses are small not because of tiny Yukawa couplings or a tiny vev of a new Higgs doublet [7]. In fact, we take the Yukawa couplings to be of order one. The smallness of the light neutrino masses are due to the cancellation in the Dirac neutrino mass matrix, making $m_D \sim \mathcal{O}(10^{-4})$ GeV and giving rise to light neutrino masses $m_\nu \sim m_D^2/M$ where M is the RH Majorana neutrino mass. Thus with M in the EW scale, we get the light neutrino masses in the correct range of $10^{-2}-10^{-1} \text{ eV}$.

Our work is presented as follows: In section 2, we present the model and the formalism. In section 3, we discuss the phenomenological implications of the model, especially how it alters the usual SM Higgs decay modes, and its implications for the Higgs search at the LHC. Section 4 contains our conclusions.

2 Model and Formalism

2.1 Our model

Our model is based on the SM gauge symmetry $SU(3)_C \times SU(2)_L \times U(1)_Y$ supplemented by a discrete Z_2 symmetry. In addition to the SM fermions and the Higgs doublet H , we introduce three RH neutrinos N_{Ri} , where $i = 1, 2, 3$, and two additional Higgs doublets H_1 and H_2 , with vevs at the EW scale. All the SM particles are even under the Z_2 symmetry, while the three RH neutrinos and the two new Higgs doublets H_1 and H_2 are odd under Z_2 . The Z_2 symmetry is softly broken by the bilinear Higgs terms. With this symmetry, the Yukawa interactions are given by

$$\mathcal{L}_{\text{SM Yukawa}} = \bar{q}_L y_u u_R \tilde{H} + \bar{q}_L y_d d_R H + \bar{l}_L y_L e_R H + h.c., \quad (1)$$

where the fermion fields represent three families, and y_d , y_u , and y_l represent three corresponding Yukawa coupling matrices.

$$\mathcal{L}_{\text{New Yukawa}} = \bar{l}_L f_{1\nu} N_R \tilde{H}_1 + \bar{l}_L f_{2\nu} N_R \tilde{H}_2 + h.c., \quad (2)$$

$$\mathcal{L}_{\text{Maj}} = \frac{1}{2} M_{\text{Maj}} N_R^T C^{-1} N_R. \quad (3)$$

Note that from the above equations, the 6×6 neutrino mass matrix is obtained to be

$$M_\nu = \begin{pmatrix} 0 & m_D \\ (m_D)^T & M_{\text{Maj}} \end{pmatrix}. \quad (4)$$

The 3×3 Dirac mass matrix is given by

$$m_D = \frac{1}{\sqrt{2}} (f_{1\nu} v_1 + f_{2\nu} v_2). \quad (5)$$

Here v_1 and v_2 are the vevs of the new Higgs fields H_1 and H_2 . For the mass scales in which $m_D \ll M_{\text{Maj}}$, the 3×3 light neutrino mass matrix is given by

$$m_\nu^{\text{light}} = -m_D M_{\text{Maj}}^{-1} (m_D)^T. \quad (6)$$

Note that experimentally masses of the light neutrinos are in the 10^{-1} – 10^{-2} eV range. Thus with M_{Maj} in the EW scale, the matrix m_D needs to be in the scale of 10^{-4} GeV. Since the vevs v_1 and v_2 are in the EW scale, we can get m_D in the 10^{-4} GeV scale by assuming the Yukawa couplings to be very tiny, of order 10^{-6} . Such a path, similar to the usual see-saw, will not lead to any interesting implications for neutrino physics in the TeV scale. Instead we assume that the Yukawa couplings $f_{1\nu}$ and $f_{2\nu}$ are $\mathcal{O}(1)$, and these Yukawa couplings and vevs v_1 and v_2 are finely tuned to get m_D in the 10^{-4} GeV. This is our approach to the smallness of the light neutrino mass scale. As we will see, this gives interesting implication for neutrino physics at the TeV scale, and can be explored at the LHC.

2.2 Higgs potential

Now we discuss the Higgs sector of the model. In addition to the usual SM Higgs H two other Higgs doublets H_1 , H_2 are required in this model. These two new Higgs doublets couple only to the neutrinos, and this is imposed using the Z_2 symmetry. It is the cancelation of contributions to the Dirac neutrino mass from these two new doublets that enable the use of fine tuning.

We assume that the Z_2 symmetry is softly broken by the bilinear terms in the Higgs Potential. The two new doublets will mix with the SM Higgs doublet, and as we will see, this will produce entirely new signals for the SM Higgs boson decays. The Higgs potential is given by

$$V_{\text{Higgs}} = V_{\text{Higgs}}^{(2)\text{even}} + V_{\text{Higgs}}^{(2)\text{odd}} + V_{\text{Higgs}}^{(4)\text{even}}, \quad (7)$$

$$V_{\text{Higgs}}^{(2)\text{even}} = \mu_H^2 H^\dagger H + \mu_1^2 H_1^\dagger H_1 + \mu_2^2 H_2^\dagger H_2 + \mu_{12}^2 (H_1^\dagger H_2 + h.c.), \quad (8)$$

$$V_{\text{Higgs}}^{(2)\text{odd}} = \mu_{H1}^2 (H^\dagger H_1 + h.c.) + \mu_{H2}^2 (H^\dagger H_2 + h.c.). \quad (9)$$

Note that the odd part of the potential breaks the Z_2 symmetry softly. This will have interesting implications for the SM Higgs boson decays.

$$\begin{aligned} V_{\text{Higgs}}^{(4)\text{even}} = & \lambda (H^\dagger H)^2 + \lambda_1 (H_1^\dagger H_1)^2 + \lambda_2 (H_2^\dagger H_2)^2 \\ & + \lambda_{1122} (H_1^\dagger H_1) (H_2^\dagger H_2) + \lambda_{HH12} (H^\dagger H) (H_1^\dagger H_2 + h.c.) \\ & + \lambda_{HH22} (H^\dagger H) (H_2^\dagger H_2) + \lambda_{1112} (H_1^\dagger H_1) (H_1^\dagger H_2 + h.c.) \\ & + \lambda_{HH11} (H^\dagger H) (H_1^\dagger H_1) + \lambda_{2212} (H_2^\dagger H_2) (H_1^\dagger H_2 + h.c.) \\ & + \lambda_{12} (H_1^\dagger H_2 + h.c.)^2 + \lambda_{H1} (H^\dagger H_1 + h.c.)^2 + \lambda_{H2} (H^\dagger H_2 + h.c.)^2 \\ & + \lambda_{H1H2} (H^\dagger H_1 + h.c.) (H^\dagger H_2 + h.c.). \end{aligned} \quad (10)$$

Since there are three Higgs doublets, after EW symmetry breaking, there will remain a pair of charged Higgs (H^\pm, H'^\pm), five neutral scalar Higgses ($h', h'_1, h'_2, H'_1, H'_2$), and two neutral pseudoscalar Higgses (A'_1, A'_2). Due to the breaking of the Z_2 symmetry, there is mixing within each of these three groups of Higgses (but not between groups). We denote the mass eigenstates of the five neutral Higgses by h , h_{10} , h_{20} , H_{10} , and H_{20} .

2.3 Mixing between the light and heavy neutrinos

In our model, we are considering a scenario in which the three RH neutrinos have masses in the EW scale with $\mathcal{O}(1)$ Yukawa couplings with the light LH neutrinos. They will also mix with the light neutrinos, and thus will participate in the gauge interactions. LEP has searched for such RH neutrinos. Before we discuss these constraints, let us first consider the mixing between the light neutrinos and the RH neutrinos. Using the observed values of the light neutrino masses and mixings, we can make a reasonable estimate of the mixing between the LH and RH neutrinos as follows. We use the normal hierarchy for the light

neutrino masses with the values

$$m_{\nu\text{Eigenvalues}}^{\text{light}} = \text{Diag}(m_{\nu_1}, m_{\nu_2}, m_{\nu_3}) = \text{Diag}(0, 8.71, 49.3) \times 10^{-12} \text{ GeV}. \quad (11)$$

The mixing matrix $R_{\nu\nu}$ follows the standard parametrization. The angles θ_{12}, θ_{23} are the central values, and θ_{13} is the maximal value allowed by current experiment [8].

$$(\theta_{12}, \theta_{23}, \theta_{13}) = (0.601, 0.642, 0.226), \quad (12)$$

$$R_{\nu\nu} = \begin{pmatrix} 0.804 & 0.551 & 0.223 \\ -0.563 & 0.585 & 0.584 \\ 0.190 & -0.595 & 0.781 \end{pmatrix}. \quad (13)$$

The three possible CP-violating phases are assumed to be zero. From the above mass eigenvalues and the mixing matrix, we can calculate the light neutrino mass matrix using

$$(R_{\nu\nu})^T m_{\nu}^{\text{light}} R_{\nu\nu} = m_{\nu\text{Eigenvalues}}^{\text{light}}. \quad (14)$$

For simplicity, we assume that the 3×3 RH Majorana mass matrix M_{Maj} to be proportional to the unit matrix,

$$M_{\text{Maj}} = \text{Diag}(M, M, M). \quad (15)$$

As a consequence of this choice for M_{Maj} and having a symmetric m_D , the mixing matrix among only the generations of heavy neutrinos is equivalent to the mixing matrix among only the generations of light neutrinos $R_{NN} = R_{\nu\nu}$. Using the above numbers and choosing $M = 100 \text{ GeV}$, we can now calculate numerically the 3×3 Dirac neutrino mass matrix from the equation

$$m_{\nu}^{\text{light}} = -m_D M_{\text{Maj}}^{-1} m_D^T. \quad (16)$$

There are four sets of real solutions for m_D . Only two sets of solutions are shown in Eqs. (17) and (18). The other two are just the negatives of these two sets.

$$m_D^{\text{Set } 1} = \begin{pmatrix} -1.25 & -1.87 & -0.267 \\ -1.87 & -3.42 & -2.20 \\ -0.267 & -2.20 & -5.36 \end{pmatrix} \times 10^{-5} \text{ GeV}, \quad (17)$$

$$m_D^{\text{Set } 2} = \begin{pmatrix} -0.543 & -0.0280 & 2.20 \\ -0.0280 & 1.40 & 4.25 \\ 2.20 & 4.25 & 3.27 \end{pmatrix} \times 10^{-5} \text{ GeV}. \quad (18)$$

Using the solutions for m_D and M_{Maj} , we can now use the full 6×6 neutrino mass matrix and calculate the full mixing matrix Q and the mixing angles between the heavy and light neutrinos.

$$M^{\text{Full}} = \begin{pmatrix} 0_{3 \times 3} & m_D \\ m_D^T & M_{\text{Maj}} \end{pmatrix}, \quad Q^{-1} M^{\text{Full}} Q = M_{\text{Eigenvalues}}^{\text{Full}}. \quad (19)$$

Table 1: Mixing angles between the light neutrinos (subscripts 1, 2, 3) and the heavy neutrinos (subscripts 4, 5, 6).

$\times 10^{-7}$	θ_{14}	θ_{15}	θ_{16}	θ_{24}	θ_{25}	θ_{26}	θ_{34}	θ_{35}	θ_{36}
Set 1	1.2	1.9	0.26	1.9	3.4	2.2	0.26	2.2	5.3
Set 2	0.55	0.36	-2.2	0.034	-1.4	-4.2	-2.2	-4.2	-3.2

It turns out that

$$Q \approx \begin{pmatrix} R_{\nu\nu} & Q_{\nu N} \\ Q_{N\nu} & R_{NN} \end{pmatrix}, \quad Q_{\nu N} \approx Q_{N\nu}. \quad (20)$$

For solution set 1, the full rotation matrix is

$$Q^{\text{Set 1}} = \begin{pmatrix} 0.80 & 0.55 & 0.22 & \begin{pmatrix} 3.1 \times 10^{-3} & 1.6 & 1.6 \\ 3.513 \times 10^{-3} & 1.7 & 4.1 \\ -2.5 \times 10^{-3} & -1.8 & 5.5 \end{pmatrix} \times 10^{-7} \\ -0.56 & 0.59 & 0.58 & 0.81 & 0.55 & 0.22 \\ 0.19 & -0.60 & 0.78 & -0.56 & 0.59 & 0.58 \\ \begin{pmatrix} 1.1 \times 10^{-4} & -1.6 & -1.6 \\ 1.3 \times 10^{-4} & -1.7 & -4.1 \\ -8.8 \times 10^{-5} & 1.8 & -5.5 \end{pmatrix} \times 10^{-7} & 0.19 & -0.60 & 0.78 \end{pmatrix}. \quad (21)$$

For solution set 2, the full rotation matrix is

$$Q^{\text{Set 2}} = \begin{pmatrix} 0.80 & 0.55 & 0.22 & \begin{pmatrix} 4.1 \times 10^{-3} & 1.6 & -1.6 \\ 3.9 \times 10^{-3} & 1.7 & -4.1 \\ -5.7 \times 10^{-3} & -1.8 & -5.5 \end{pmatrix} \times 10^{-7} \\ -0.56 & 0.59 & 0.58 & 0.80 & 0.55 & 0.22 \\ 0.19 & -0.60 & 0.78 & -0.56 & 0.590 & 0.58 \\ \begin{pmatrix} -8.9 \times 10^{-4} & -1.6 & 1.6 \\ -7.9 \times 10^{-4} & -1.7 & 4.1 \\ 1.4 \times 10^{-3} & 1.8 & 5.5 \end{pmatrix} \times 10^{-7} & 0.19 & -0.60 & 0.78 \end{pmatrix}. \quad (22)$$

As can be seen on Table 1, the mixing between the heavy and light neutrinos is extremely small.

3 Phenomenological implications

In this section, we discuss the phenomenological implications of our model. We are considering RH neutrinos at the EW scale. Their mass can be below the W boson mass. Thus they can be searched for at LEP, Tevatron, and at the LHC. First we discuss the constraints that already exist from the search at LEP.

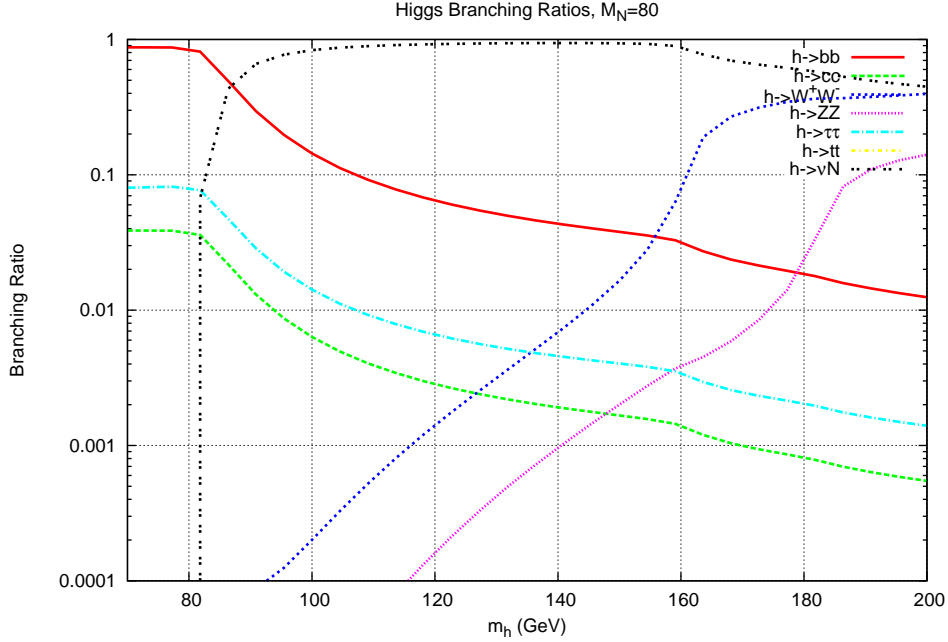


Figure 1: Branching ratios of $h \rightarrow 2x$ with the coupling between N_R and ν_L , $f_{1\nu} + f_{2\nu} = 1$.

3.1 LEP constraints

Searches for N_R have been conducted at LEP in the channel $e^+e^- \rightarrow Z \rightarrow N_R \nu_l$, with N_R subsequently decaying to W^+e^- or $Z\nu$. This experiment puts limits on the mixing angle θ between the heavy and the light neutrinos $\sin^2 \theta < 10^{-4}$ for $3 \text{ GeV} < M_N < 80 \text{ GeV}$, and $\sin^2 \theta < 0.1$ for $M_N > 80 \text{ GeV}$ [9]. As we discussed in previous section, the mixing angles θ between the light and heavy neutrinos are extremely small, ranging between $\sim 10^{-8}$ to 10^{-6} . Thus, in our model, LEP constraints allow small masses for the heavy Majorana neutrinos.

3.2 Higgs decays and Higgs signals

In our model, the Yukawa couplings between the light neutrinos, the heavy Majorana neutrinos and the new Higgs fields H_1 and H_2 are $\mathcal{O}(1)$. The SM Higgs H mixes with the new Higgses, and these mixings are naturally large. Thus, for $M_N < M_h$, the SM Higgs will dominantly decay to a light ν and N_R , as soon as this decay mode becomes kinematically allowed, because the coupling for this decay mode is much larger than the usually dominant $b\bar{b}$ mode, or even the WW mode. The branching ratios for the various Higgs decay modes are shown in Fig. 1 for $M_N = 80 \text{ GeV}$, for the Yukawa couplings, and $f_{1\nu} = f_{2\nu} = 1$. As can be seen from the plot, as soon as the decay mode $h \rightarrow \nu N_R$ becomes kinematically allowed, this mode totally dominates over the usual $b\bar{b}$ mode, and is larger than the usually dominant WW mode even beyond the WW threshold. Thus in our model, the SM Higgs decay mode is greatly altered. A second plot is shown for Yukawa couplings equal to $1/14$ in Fig. 2

At hadron colliders, the SM Higgs boson is dominantly produced via gluon fusion with

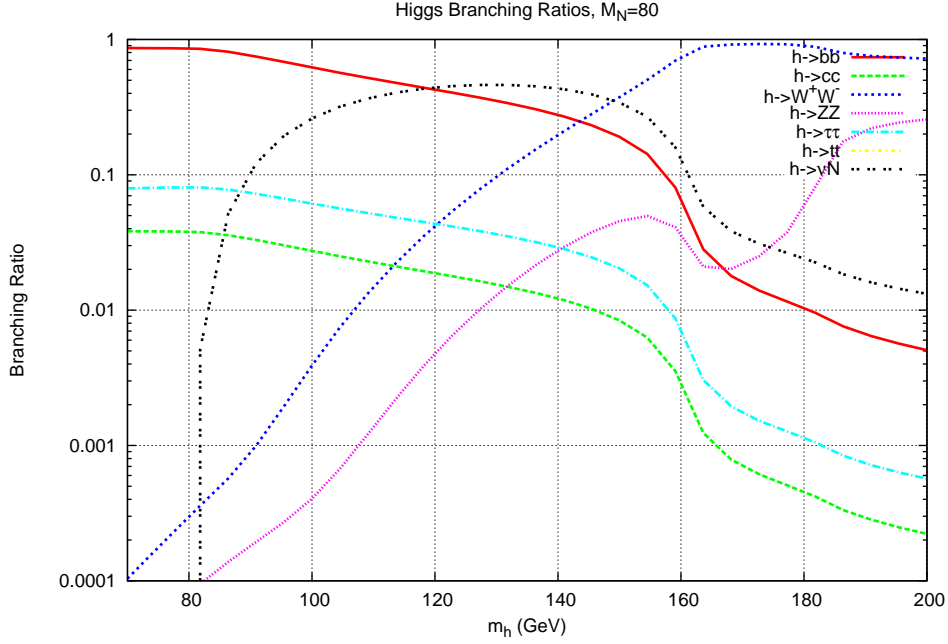


Figure 2: Branching ratios of $h \rightarrow 2x$ with $f_{1\nu} + f_{2\nu} = \frac{1}{7}$.

the top quark in the loop. In our model, because of the mixing of H with H_1 and H_2 , the lightest mass neutral scalar Higgs decays dominantly as $h \rightarrow \nu N_R$. The final state signal will depend on the decay modes of N_R . Two of the allowed decay modes of N_R are shown in Fig. 3. The 3-body decay mode $N_R \rightarrow \nu \bar{b}b$ is completely dominant over the 2-body decay mode lW or νZ . This is because the 2-body decay is suppressed by the tiny mixing angle, $\theta \sim 10^{-6}$ or smaller. Thus the final state signals for the Higgs bosons at the LHC, in our model, is $\bar{\nu}\nu\bar{b}b$. Collider signals will include large missing energy and 2 hard b-jets.

Using Madgraph, we generated events for $pp \rightarrow \bar{\nu}\nu\bar{b}b$ in the SM for LHC at 14 TeV, 7 TeV, and Tevatron. Using the cuts $\cancel{E}_T > 30$ GeV, and the p_T for each b-jet to be greater than 20 GeV, we find the cross section to be ~ 13 pb, for the LHC at 14 TeV. This provides a reasonable estimate of the background. The cross section for Higgs production at the LHC at 14 TeV is ~ 50 pb for a 120 GeV Higgs. For a large mass range of the Higgs boson in our model, the branching ratio, $BR(h \rightarrow \nu N_R) \sim 100\%$. Thus, prior to any cuts on the signal, this mode is observable at the LHC, and stands out over the SM background. A summary for different energies is given in Table 2. The Higgs production at the Tevatron is taken from [10]. For the LHC we used [11].

3.3 $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ Search at Tevatron

The D0 collaboration at the Tevatron has searched for the SM Higgs boson in the $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ channel using 5.2 fb^{-1} of data. With both b 's being tagged and a $\cancel{E}_T > 40$ GeV and $p_T > 20$ GeV for the b-jets, they expect about 5 events for the ZH mode. However, there

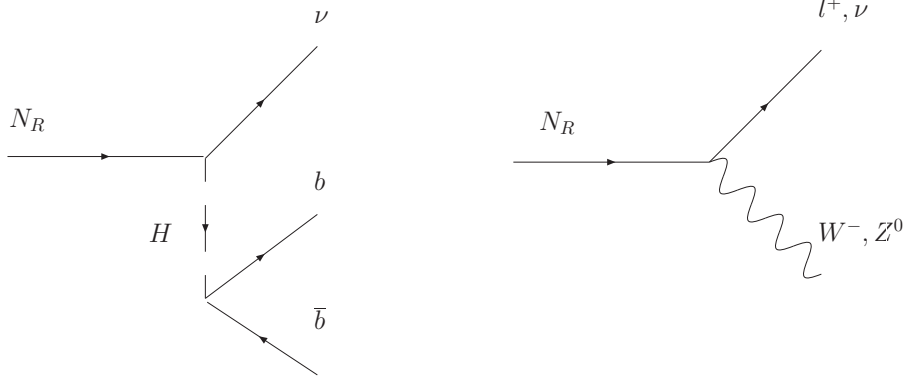


Figure 3: Decay modes of N_R .

Table 2: Collider Searches for $m_h = 120$ GeV.

Collider	\sqrt{s} Energy	Background	Signal
LHC	14 TeV	13 pb	50 pb
LHC	7 TeV	2.4 pb	30 pb
Tevatron	2 TeV	240 fb	1 pb

is a large SM background arising mainly from $W + \text{jets}$, $Z + \text{jets}$, and $t\bar{t}$. The estimated background with these cuts is about 538 ± 93 events, while they observe 514 events. Thus the SM signal from ZH production for this $\nu\bar{\nu}b\bar{b}$ mode is not observable with the current Tevatron data. However in our model, depending on the $BR(h \rightarrow \nu N_R)$, this signal is much larger and may be observable, especially as luminosity accumulates in the coming year. Other possibilities for our model are that the RH neutrinos could decay via a charged Higgs.

3.4 N_R Decays via Charged Higgs

For a sufficiently light $m_{H^\pm} < 250$ GeV, the decay $N_R \rightarrow \nu_\tau \tau^+ \tau^-$ via a charged Higgs becomes important. Taking the Yukawa couplings to be order one, and the mixing to be maximal between the three Higgs doublets, the decay rates for the N_R decays are shown in Table 3. Taking the tau $p_T > 20$ GeV and $\cancel{E}_T > 30$ GeV, the cross section for $p\bar{p} \rightarrow \nu\bar{\nu}\tau^+\tau^-$ at the Tevatron is 45 fb (123 fb at the LHC for 7 TeV collisions). This background is much smaller than $pp \rightarrow \bar{b}b\nu\bar{\nu}$ background, as it is a leptonic (not QCD) process. This signature, two high p_T taus plus missing energy, may be easier to see.

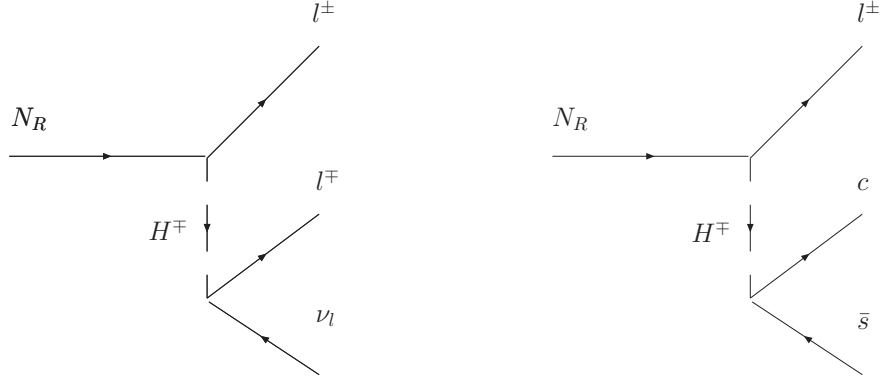


Figure 4: Decay modes of N_R through a charged Higgs H^\mp .

Table 3: Decay Rates of N_R for $M_N = 80$ GeV, $M_h = 120$ GeV.

Decay Mode	$\Gamma(N_R \rightarrow 3x)$ (GeV)	m_{H^\pm} (GeV)	BR
$N_R \rightarrow \nu b \bar{b}$	1.56×10^{-9}	200	43.8%
$N_R \rightarrow \nu_\tau \tau^+ \tau^-$	1.32×10^{-9}	200	37.0%
$N_R \rightarrow \tau c \bar{s}$ (or $\bar{c} s$)	5.80×10^{-10}	200	16.3%
$N_R \rightarrow \nu c \bar{c}$	6.60×10^{-11}	200	1.85%
$N_R \rightarrow \nu_\mu \mu^+ \mu^-$	4.00×10^{-11}	200	1.12%
$N_R \rightarrow \nu b \bar{b}$	1.56×10^{-9}	250	63.6%
$N_R \rightarrow \nu_\tau \tau^+ \tau^-$	5.62×10^{-10}	250	22.9%
$N_R \rightarrow \tau^- c \bar{s}$ (or $\tau^+ \bar{c} s$)	2.26×10^{-10}	250	9.21%
$N_R \rightarrow \nu c \bar{c}$	6.60×10^{-11}	250	2.69%
$N_R \rightarrow \nu_\mu \mu^+ \mu^-$	2.45×10^{-11}	250	1.65%

4 Conclusions

We have proposed a new approach for understanding of the tininess of the light neutrino masses. We extend the SM gauge symmetry by a discrete Z_2 symmetry, and the particle content by adding three right handed neutrinos and two additional Higgs doublets. These new Higgs doublets couple only to the neutrinos. The tiny neutrino masses are generated via the see-saw mechanism with the right handed neutrino mass matrix at the EW scale, and the Dirac neutrino mass matrix at the 10^{-4} GeV scale. The Dirac neutrino mass matrix gets contribution from the two new EW Higgs doublets with vevs at the EW scale. The Yukawa couplings are of order one, and the two EW contributions are fine tuned to achieve the Dirac neutrino mass matrix at the 10^{-4} GeV level. The model links neutrino physics to collider physics at the TeV scale. The SM Higgs decays are drastically altered. For a wide range of the Higgs mass, it decays dominantly to $\nu_L N_R$ giving rise to the final state $\bar{\nu} \nu b \bar{b}$, or

$\bar{\nu}\nu\tau^+\tau^-$. This can be tested at the LHC and possibly at the Tevatron.

Acknowledgments

We thank K. S. Babu, W.A. Bardeen, B. Dobrescu, C. T. Hill and A. Khanov for useful discussions. Part of this work was done during our visit to Fermilab in Fall, 2009. We thank the Fermilab Theory Group for warm hospitality and support during this visit. This work is supported in part by the United States Department of Energy, Grant Numbers DE-FG02-04ER41306 and DE-FG02-04ER46140.

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